Technological diffusion as a process of societal embedding: Lessons from historical automobile transitions for future of electric mobility

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1. Introduction

This article expands the theoretical toolkit for assessing the topic of technological diffusion by developing a societal embedding perspective. It explores societal embedding with two historical case studies of automobile diffusion in the Netherlands and United States, and applies it to contemporary electric mobility at a global scale. Both diffusion and automobility—defined as the global system supporting privately owned and used, fossil fuel powered passenger vehicles (Urry 2004; Sovacool and Axsen 2018)—are gaining importance in the context of climate change, where emissions must peak by 2020 and then rapidly decline in order to have a decent chance of reaching the 2^0 C target (Anderson and Bows, 2012; Rockstrom et al. 2017). Approximating this ambitious goal will require not only rapid diffusion of low-carbon technologies in the transportation sector, but also the development of new socio-technical systems (Geels et al., 2017; Eyre et al., 2018).

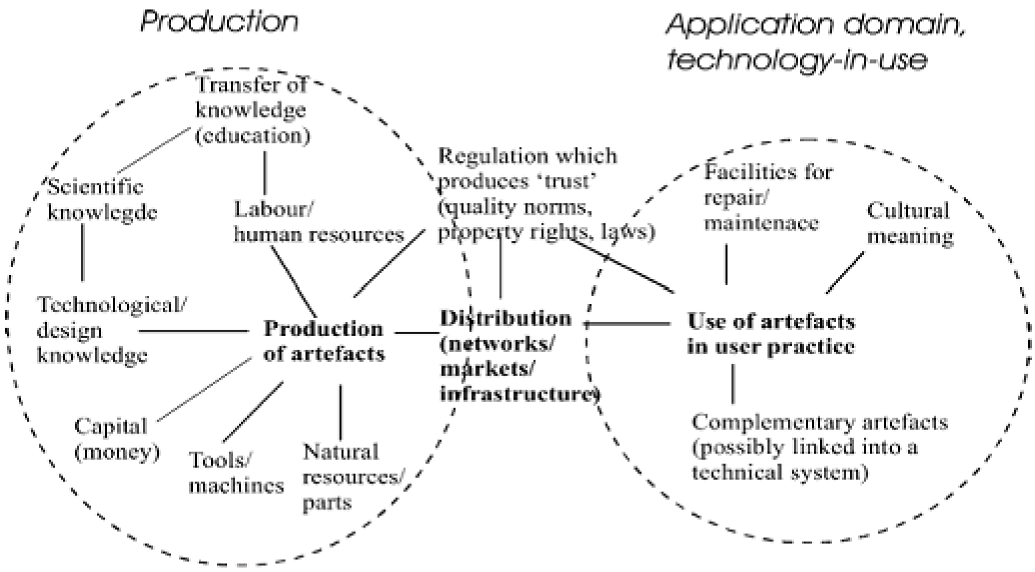
Studies of eco-innovations (e.g. Tsoutsos and Stamboulis, 2005; Kemp and Volpi, 2008; Rao and Kishore, 2010; Dijk et al., 2013; Karakaya et al., 2014) have identified various drivers and barriers of technological diffusion, often in the form of lists of factors such as price/performance improvements, information availability, or attitudes and motivations, in addition to upfront investments, access to capital, or government policies (e.g. subsidies, taxes, standards, regulations). But since diffusion trajectories of most eco-innovations are still in early stages, they do not yet offer robust empirical data to investigate entire diffusion pathways. Most of these studies use a particular conceptualization, which understands technological diffusion as an *adoption* process in which a population of consumers purchase technologies at different moments in time, such as “early adopters” or “laggards” (Rogers, 2003; Arthur 1988).

Despite their value, adoption models have some under-developed dimensions (Schot, 1992; Schot, 1998; Geels and Johnson, 2018). First, adoption models often privilege one kind of actor (adopters) and downplay the role of other social groups (although most eco-innovation studies note the role of policy). These adopters are mostly conceptualized as purchasers of technologies, with limited attention being given to actual *use* or broader systems that underpin functionalities. Second, many adoption models are paradoxically static, assuming that the population of adopters is given and can be characterized in terms of socio-economic, socio-psychological or other characteristics.[1] The diffusion environment is also seen as relatively static, e.g. as network structures through which information flows (in epidemic models), as market structures (made up by individuals with given socio-economic characteristics), or as barriers to adoption (Eyre, 1997). Third, while much diffusion research focuses on speed and S-shaped market patterns (exemplified by curve-fitting exercises), it has less to say about the directionality of the diffusion process and the *shape* of socio-technical systems, in which new technologies ultimately become embedded. The reason is that they pay limited attention to activities and struggles during diffusion paths that shape infrastructures, policies, cultural meanings, user practices and specific functionalities, which make up broader socio-technical systems (Geels, 2004; Elzen et al., 2004).

This paper does not aim to discredit existing adoption models of diffusion. These models provide useful insights for understanding the rate of diffusion of many product and process technologies. However, these models provide a somewhat limited understanding for the diffusion of new technologies that have the potential for contributing to a transition of the entire socio-technical system in which they function (See Figure 1). Such a system is a configuration of actors (their knowledge and skills), technologies (products, infrastructures), and institutions (regulations, cultural symbols, markets) fulfilling a societal function such as mobility or comfort (Rip and Kemp, 1998; Geels, 2004). This article therefore aims to develop a broader understanding of diffusion (touching upon topics such as technological innovation) and sustainability transitions (qualitative long-term changes in socio-technical systems).

[1] An exception is the small literature stream on co-evolutionary learning between users and suppliers during diffusion processes (Windrum and Birchenhall; 1998; Dijk *et al.*, 2013).

Figure 1: Basic elements and resources of socio-technical systems



Source: Geels (2004: 900)

From the perspective adopted in this paper, technological diffusion can thus be understood as a process of co-construction of the entire configuration of socio-technical systems, including the focal technology and the environments in which it will function. Focusing on this co-construction process, the paper's specific contribution is to apply a conceptualization of technological diffusion of system-changing technologies as a process of *societal embedding*. We investigate how new technologies—in this case conventional automobiles, the most visible part of a system of global automobility —co-evolved with user practices, broader cultural meanings, policies, infrastructures and transnational actor communities in two socioeconomic contexts, the United States and the Netherlands.

In applying and advancing societal embedding in this way, the paper aims to make three contributions. Conceptually, societal embedding helps address the under-developed dimensions in adoption models, described above: 1) it accommodates users as well as other social groups, 2) it shows that characteristics of socio-technical system are *not* known in advance; instead, preferences, actors, symbols, markets, regulations, infrastructures are constructed and solidify during the technological diffusion process

(Coombs et al., 2001; Oudshoorn and Pinch, 2003), 3) it demonstrates that societal embedding is full of choices and struggles that affect the directionality of innovation (Stirling, 2008), leading to the emergence of regional differences in markets and socio-technical systems over time. Second, also conceptually, societal embedding offers more nuance to debates within the sustainability transitions community about path dependence and lock-in effects, showing that they need not always occur only on the "supply side," e.g. through technologically deterministic notions of "momentum" created by electric utility networks (Hughes, 1983) or the "lock-in" from fossil-fueled transport infrastructure (Unruh 2000). Societal embedding shows that path dependence or lock-in can also occur on the "demand side" via embedded user expectations, business practices, cultural norms, regulations, and the power of transnational actors. Finally, and empirically, we are the first to apply the concept of societal embedding to transport and automobility and do so through a comparative cross case analysis with clear connections to modern social problems such as the decarbonisation of passenger mobility.

The paper is structured as follows. Section 2 introduces the societal embedding framework. Section 3 discusses methodology with regard to our choice for two historical case studies of the diffusion of automobiles in the USA (1880s-1970) and the Netherlands (1890s-1970). Section 4 presents the dynamics of societal embedding for both cases. Section 5 discusses comparative insights from the historical cases with regard to our societal embedding framework. Section 6 then applies the conceptual framework to discuss implications for sustainability transitions, especially those related to electric vehicles, which are illustrated with examples from multiple countries. To use parlance from the methodology literature, we conduct a plausibility probe, utilizing "preliminary studies on relatively untested theories and hypotheses to determine whether more intensive and laborious testing is warranted" (George and Bennett, 2005: 75). This means our study is both confirmatory (exploring usefulness of framework with two historical cases) as well as exploratory (generating new questions and applications to EVs) (Sovacool et al., 2018a). Section 7 concludes.

2. Societal embedding in socio-technical transitions

The societal embedding framework maintains that the diffusion of innovations includes not only adoption and purchase, but also embedding in, and construction of, broader social domains. The process of societal embedding can be conceptualized as an active alignment process between the innovation and its environments. In other words: "Technology adoption is an active process, with elements of innovation in itself. (…) Behaviours, organization and society have to re-arrange themselves to adopt, and adapt to, the novelty. Both the technology and social context change in a process that can be seen as co-evolution" (Rip and Kemp, 1998: 389). Because of its processual orientation, the societal embedding perspective does not conceptualize an external environment as simply replete with "barriers," but as a dynamic force that can exert positive and negative pressures on new technologies.

Deuten et al. (1997) introduced the societal embedding framework and initially distinguished three domains: a business environment (industry structures, markets), a policy environment (formal rules, regulations), and a cultural environment (cultural discourses, norms, social acceptance). Later work from Geels and Johnson (2018), Geels et al. (2018), and Mylan et al. (2018) has added the specific user environment (user routines, beliefs, skills, and practices). In this paper, we propose to add the transnational environment as a fifth domain, because the build-up of a new socio-technical system in a specific place, for example a country, shapes experiences and developments in other places and leads to build up of international standards.

This results in a societal embedding framework constituted by five pertinent dimensions for the diffusion of new innovations:

1. *Embedding in user environments* goes beyond purchase activities, involving the integration of new technologies into user practices and the development of new preferences, routines, habits and even values (Gram-Hanssen, 2008). The user environment also extends beyond adopters (in this case drivers of cars) to include other actors related to the automobility system such as cyclists or pedestrians, police officers, car salespersons, government and urban planners, and even writers for the mass media (to name some). Social historians of technology (Nye, 1990; Fischer, 1992; De la Bruheze and Oldenziel, 2008) have shown that new technologies need to be "domesticated" and transformed from unfamiliar and possibly threatening things to familiar objects embedded in the routines and practices of everyday life. The literature on domestication (Silverstone and Hirsch, 1992; Lie and Sørensen, 1996) suggests that this involves three sub-processes: *cognitive work*, which includes learning about the artefact and the development of new competencies; *symbolic work*, which refers

to sense-making and the articulation of new interpretive categories; *practical work*, in which users adjust everyday routines and practical considerations. These processes resonate with social practice theory, which also suggest that appropriation of new technologies involves changes in meanings, competencies, and material elements (Shove et al., 2012). Users are thus actively involved in technological diffusion, potentially playing a variety of roles, e.g. user-intermediaries, user-citizens and user-consumers (Schot et al., 2016; Kanger and Schot 2016).

2. *Embedding in the business environment* refers to the development of industries, business models, supply and distribution chains, and repair facilities. If innovations are pioneered by new entrants, widespread diffusion may lead to the downfall of established firms (Christensen, 1997) or to the reorientation of incumbents (Penna and Geels, 2015).
3. *Cultural embedding* refers to the articulation of positive discourses, narratives, and visions that enhance cultural legitimacy and societal acceptance of new technologies (Geels and Verhees, 2011). Positive cultural discourses (and perhaps negative cultural discourses about existing technology) are important for diffusion, because they can influence consumer preferences, expectations, political support, and access to financial resources (Lounsbury and Glynn, 2001; Jasanoff and Kim, 2015). Cultural embedding may, however, be a contested process with discursive struggles between proponents and opponents (Geels et al., 2007).
4. *Regulatory embedding* refers to the variety of policies that shape production, markets and use of new technologies, e.g. safety regulations, reliability standards, adoption subsidies, demonstration projects, and infrastructure investment programs (Ashford et al., 1985; Taylor et al., 2005). Substantial policy changes—especially shocks and discontinuities—can also affect the regulatory environment, and usually entail power struggles, making technology diffusion and new system creation deeply political processes (Meadowcroft, 2009; Kern, 2011).
5. *Embedding in the transnational community* refers to the creation of shared understanding in a community of experts related to new technologies that transcends the borders of a single place, often a country. This transnational

community serves as an arena for mutual learning, exchange of experience, consultation and negotiation, and consensus-formation about different standards (this has been argued from a transnational history perspective see Saunier, 2013; Kaiser and Schot, 2014; for automobility Mom, 2015; and for sustainability transitions Fuenfschilling and Binz, 2018). From the perspective of a single country a transnational community can be viewed as an external selection environment shaping the evolution of national socio-technical systems.

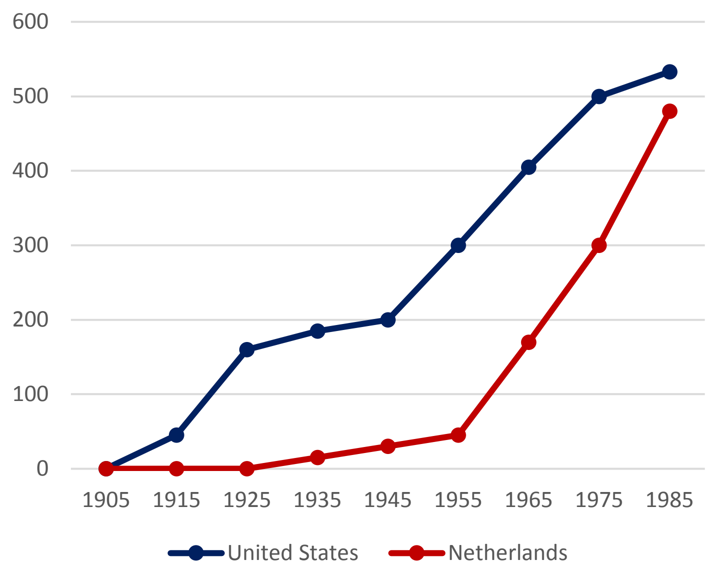
These dimensions of societal embedding suggest that technological diffusion is an active and contested process, full of choices, debates, and struggles. So far, the concept has been recently applied to food (Mylan et al., 2018), biomass district heating (Geels and Johnson, 2018), and energy efficiency (Geels et al., 2018), but not to transport, automobility, or electric mobility.

When applying our societal embedding framework, we also connect it to two other meaningful concepts: that of “transitions,” and that of “phases.” By “transitions”, we mean shifts from one socio-technical system or regime to another (Schot et al., 2016). By “phases”, we refer to three stages in transitions as suggested by Schot et al. (2016) and Kanger and Schot (2016): emergence (sometimes called “start-up”), acceleration, and stabilization. Emergence refers to the early stages of a new technology when it operates in a protective space and begins to improve in terms of price, performance, or other attributes. Acceleration refers to when the new technology enters the mainstream market and starts to compete with other incumbent (and novel) technologies. Increasing diffusion is accompanied by changes in both user practices and technical functions. Stabilization refers to technology reaching its peak and maturation, resulting in incremental change. Technical, user, business, cultural, regulatory, and transnational dimensions become well-aligned and resistant to change, enabling a rapid increase in the number of users. Admittedly, other phases after stabilization, such as “decline” (Schot, 1992), “stagnation,” (Sovacool et al., 2018b), or “destabilization” (Turnheim and Geels, 2012) exist, but are outside the remit of this particular study.

3. Research design and methods: Historical cross case comparison

To apply the societal embedding perspective, we use a historical cross case comparison of the diffusion of automobiles in the USA (1880s-1970) and the Netherlands (1890s-1970). We chose a qualitative case study comparison because this is well suited for rich, qualitative and processual studies of phenomena in real-world environments (Yin, 2014). The USA and Netherlands were chosen because they are clear-cut examples of countries where automobility became entrenched (so similarity in cases) but at different times (United States preceded the Netherlands). One interesting contrast is the larger geographic space (and thus travel distances involved) in the United States, compared with the smaller spaces and travel times in the Netherlands. Another interesting contrast, which we cannot systematically elaborate because of space constraints, is that the USA has a federalist institutional structure (in which states and local policymakers have substantial responsibilities compared to the federal level), while the Netherlands has a more centralized structure (with strong roles for the national government). Nevertheless, the USA proved to be a rapid adopter of automobiles surpassing all Western countries, including the Netherlands, already in the interwar era. However, both countries experienced an ever more rapid growth in the number adopters after World War II (see Figure 2).

Figure 2: Diffusion of automobiles in the United States and Netherlands (number of passenger cars per 1000 inhabitants), 1905-1985



Source: Modified and redrawn from Mom (2014: 289)

We believe the case study literature would call our approach a mix of "typical" yet "diverse" cases (Gerring, 2004, 2005). *Typical* case studies focus on common, frequently observed, and/or representative cases, and exemplify a stable, cross-case relationship (Sovacool et al., 2018a). *Diverse* cases attempt to demonstrate maximum variance along a relevant dimension, so that they illuminate the full range of important differences

(Sovacool et al., 2018a). Our two cases are therefore typical but not identical, as they vary in some of their features (differences in time periods of emergence and acceleration, business environments, regulations, culture, etc.) (Mom, 2015).

We use congruence analysis (Blatter and Blume, 2008; Yin, 2014) to assess the fit between the two longitudinal descriptions of the societal embedding of automobiles and the conceptual framework. We reason that if similarities in societal embedding activities can be shown in these two quite different cases it would provide stronger support for the framework by demonstrating the general scope of the embedding mechanisms underlying the overall pattern of diffusion. At the same time, we may be able to find differences which are responsible for shaping the varying rate and directionality of the diffusion process in both countries, and how the enactment of different embedding mechanisms lead to different outcomes (i.e. shape of the resulting auto-mobility system).

The case selection is also based on practical considerations: the history of the automobile has been abundantly studied in both countries and allows us to draw on secondary literature (e.g. McShane, 1997; Mom et al., 2002a, b; Schot et al., 2002; Staal, 2003; Geels, 2005; Mom and Filarski, 2008 ; Mom et al., 2009; Sovacool, 2009;; Mom, 2015; Kanger and Schot, 2016). For data-sources, we are thus in the position to rely on a synthesis of prior literature.

Although in-depth narrative descriptions would be best-suited to capture the complexities and non-linearities of temporal processes like societal embedding (Büthe, 2002; Abell, 2009), space limitations prevent use of this technique, as it is practically impossible to richly describe two 80-year cases in the space of one article. We therefore use summary tables, which for each period and country describe the main societal embedding activities and struggles. Although the summaries in the tables are stylized, we argue that the trade-off between depth and breadth is warranted for the comparative purposes of our article. These tables also allow easier comparison between the two cases, and form a pragmatic way of describing very complex, longitudinal processes.

4. Case studies: The societal embedding of American and Dutch automobiles

In this section we present our main findings, which are organized according to the three phases of emergence, acceleration, and stabilization. For each phase, the overall outcomes of the diffusion process are briefly summarized for both countries.

This is followed by a more detailed discussion of embedding activities along different dimensions. We summarize this discussion in tables that describe the main embedding activities for each period and environment.

4.1 Emergence of societal embedding in the USA (1880-1907) and Netherlands (1890s-1918)

In the second half of the 19th century the macro-trends of industrialization and urbanization created problems for the horse-drawn carriage transport in the US cities that could not be solved by optimizing the existing technology. As a response a variety of contenders emerged as possible solutions, including bicycles, trams (electric, steam) and automobiles (steam, electric, gasoline) (Geels, 2005).

In the Netherlands similar trends as well as similar responses were visible in the second half of the 19th century although the diffusion process was much slower.

In both countries, car races helped create legitimacy for cars by demonstrating technical capabilities (Rao, 1994). But races also galvanized enthusiasm, emphasizing the role of the automobile as an *adventure* machine: the exciting combination of fear and pleasure in the experience of speed (Figure 3) (Mom, 1997; Schot et al., 2002; Mom, 2015). Table 1 summarizes the main societal embedding activities in both countries for the emergence phase.

Figure 3: Car racing was exhilarating and a popular spectator sport: the Paris-Amsterdam-Paris long-distance race of 1898 (left) and speed-racing (right)

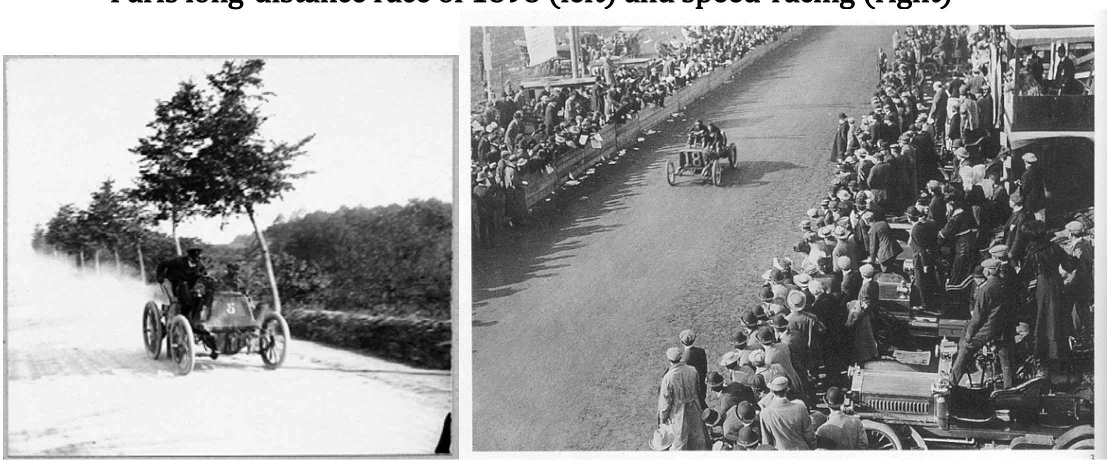


Table 1: The *emergence* of societal embedding of the automobility in United States and the Netherlands

Types of embedding	Manifestations in the United States (1880-1907)	Manifestations in the Netherlands (1890s-1918)

User environment *General trend:* car is only used for a few purposes, mainly by higher and upper middle class	Early bicycle users facilitate the emergence of the idea of individualized mobility The higher class uses the car for racing and touring Country physicians start to use the car for visits Largely because of technological instability early users define tinkering as an inseparable part of car use experience	Early bicycle users facilitate the emergence of the idea of individualized mobility The higher class uses the car mainly for racing (emphasized by NAC) and touring (emphasized by ANWB) Professionals with flexible transportation needs (doctors, salesmen, shop owners) start to adopt the car for practical purposes Largely because of technological instability early users define tinkering as an inseparable part of car use experience
Business environment *General trend:* multiplicity of different competing niches for passenger transport gradually leading to the emergence of the gasoline car as the dominant one	Different entrepreneurs advocate various niches as a solution for the crisis of the urban horse-drawn carriage regime, e.g. bicycles, trams (steam and electric), cars (steam, electric, gasoline) The creation of a large number of small car enterprises producing a wide variety of different designs and models Early attempt to monopolize the car industry: George B. Selden patents the car (1895), joins the Association of Licensed Automobile Manufacturers and starts to collect royalties from automobiles sold by the members of ALAM; he loses the appeal to Henry Ford in 1911 Self-production by talented engineers and self-repair of automobiles is highly prevalent because of the multiplicity and unreliability of basic designs, the lack of supply, fuel, repair and maintenance infrastructure and smooth asphalt roads	Early car clubs represent the needs, wants and experiences of users, establishing themselves as intermediaries between producers and users

Cultural environment *General trend:* multiplicity of competing frames because of material and discursive struggles between car advocates and its opponents	Farmers brand the car as a "devil wagon" whereas other opponents frame it as a "plaything for the rich" or a promoter of inequality (Woodrow Wilson, 1906) Car enthusiasts define the cultural meaning of the car for themselves through adventure (racing, touring) and "conspicuous consumption" (public displays) Cars also become connected to "whiteness" and meaning shaped by racism and segregation, i.e., early users are mostly white affluent men For external audiences car enthusiasts, producers and early car clubs promote the automobile as a "harbinger of modernity", a "democratic technology" or a "necessity" Manufacturers and car clubs cooperate to organize car shows (e.g. the National Automobile Show, 1900) in order to introduce the machines to the wider public Using automobiles as rescue vehicles during the San Francisco earthquake (1906) and the adoption of the car by country physicians helps to legitimate the car as a practical technology	Car enthusiasts define the cultural meaning of the car for themselves through adventure (racing, touring) and conspicuous consumption (public displays) Car races help to create legitimacy for cars by demonstrating technical capabilities
Regulatory environment *General trend:* from initially hostile responses (bans and resistance) to first attempts to integrate the car to the traffic	Initially local authorities ban experiments with self-propelling (steam) vehicles on city streets Resistance: drivers are harassed and attacked in cities and in the countryside, in some rural areas farmers organize into anti-automobile movements	Resistance: drivers are harassed and attacked in cities and in the countryside with some of the resistance being organized (e.g. anti-speed organizations lobbying for closing certain roads for cars); in 1908 a speed limit in cities is introduced of 10km.

	The creation of early car clubs (The Automobile Club of America, 1899; American Automobile Association, or AAA, in 1902) that start to lobby for favourable legislation (e.g. about raising speed limits) Some early attempts to draft local traffic regulations, e.g. William Eno's proposals being adopted in New York (1903) Early attempts by car clubs to provide maps for travellers, to put up road signs and to organize driving courses	Dutch Automobile Club (NAC) is established (1898), General Cyclists' Union (ANWB) shifts its attention to cars (early 1900s) – both start to negotiate for favourable national legislation Early improvements to local road infrastructure in and around cities, e.g. cutting down trees, various types of paving (bricks, macadam, asphalt, concrete) Early attempts from national policymakers to develop speed regulations (1904; 1908), car design requirements, traffic rules and a license system
Transnational community *General trend:* Early international learning with the centre of gravity in Europe	US car clubs become the members of international automobile organizations, the Association Internationale des Automobile Reconnus (1904) and the Ligue Internationale des Associations Touriste Car club and trade journals mediate international experience enabling the comparison of local developments to trends in other countries	ANWB becomes the early member of international automobile organizations, the Association Internationale des Automobile Reconnus (1904) and the Ligue Internationale des Associations Touriste (1899) Car clubs and trade journals mediate international experience enabling the comparison of local developments to trends in other countries: in particular, they play a role in adapting the cars designed elsewhere to Dutch conditions

Sources used for dates and activities: McShane, 1997; Zeitlin and Herrigel, 2000; Geels, 2005; Mom, 2015; Kanger and Schot, 2016; Mom et al. 2002a, b; Schot et al. 2002; Staal, 2003; Mom and Filarski, 2008; Mom et al. 2009; Franz 2004; Zylstra 2011.

4.2 Acceleration of societal embedding in the USA (1908-1945) and Netherlands (1919-1957)

Beginning in 1908 the car and especially the gasoline-based car started to become more and more prominent, as Table 2 indicates. The introduction of the Ford Motor

Company's Model T signaled a turn to an affordable middle-class car, resulting in a rapidly growing adoption in the interwar era, soon outpacing other countries. The growth slowed down towards the end of the 1920s by which more than half of the American families owned a car (Mom, 2015: 297). The Model T, in other words, offered low-cost drivers their first high style adventure machine.

In the Netherlands, also, during the interwar years the automobile became more popular, but the numbers were still small: 150,000 in total. Instead people walked longer distances, cycled much more and public transportation continued to have a large share of the transportation market. The automobile only developed into a dominant mode of transport in the Netherlands during the 1950s. Table 2 summarizes the main societal embedding activities in both countries for the acceleration phase.

Table 2: The *acceleration* of societal embedding of the automobility in United States and the Netherlands

Types of embedding	Manifestations in the United States (1908-1945)	Manifestations in the Netherlands (1919-1957)
User environment *General trend:* the take-up of the car by the upper middle class and in rural areas including an explosion in the variety of car use practices	Users actively re-design and adapt the car for various purposes (truck, van, ambulance, bus); they also create and patent a wide variety of auxiliary innovations (e.g. bumpers, windshields, auto tents) through a process of "tinkering": a practice that will be increasingly phased out by other system actors by the 1930s Users integrate cars to everyday life in various ways, creating new routines (e.g. new courtship patterns, redefinition of shopping and cooking, bulk buying, weekend city trips)	Helped by favourable national legislation (low import taxes, taxation system based on car weight) users increasingly start to adopt Ford T-s (light, powerful engine, suitable for rural roads) Users actively re-design and adapt the cars for various purposes (truck, van, ambulance, bus) Users integrate cars to everyday life in various ways, creating new or expanding existing routines (e.g. widespread weekend and holiday touring) Users experience driving by taking a bus, which is promoted by the ANWB as a form of learning about car driving
Business environment *General trend:* increasing division of	Ford introduces the first Model T, initiating the era of the automobile as a mass-produced consumer good	Automobile and touring clubs have become serious spokespersons for the industry, representing a large part of car users and

labour whereby various actors become increasingly specialized to specific tasks in relation to the automobile system	"The Big Three" (Ford, 1903; General Motors, 1908; Chrysler, 1925) come to dominate the automobile industry "Planned obsolescence": Alfred P. Sloan Jr. introduces the practice of annual changes to car models (1924) Car producers increasingly shift their attention to incremental innovations (from electric starter in 1912 to automatic transmission in 1940), gradually discouraging and phasing out user intervention Various entrepreneurs create the fuel, repair and maintenance infrastructure Various dealers and other entrepreneurs introduce new sales and financing techniques, e.g. insurance, salesrooms, and instalment financing for new cars Various entrepreneurs create specialized complementary services to the automobile system, e.g. drive-in restaurants (1921), motels (1925) and drive-in theatres (1933)	providing useful information for users Various entrepreneurs create the fuel, repair and maintenance infrastructure which, with the mediating help of ANWB, stimulates the second-hand and rental markets Various dealers and other entrepreneurs introduce new sales and financing techniques, e.g. instalment financing
Cultural environment ***General trend:*** the cultural meaning of the car stabilizes	Producers, distributors, media and users contribute to the convergence of the cultural meaning of the car around three pillars: an instrumental machine, a status object and a symbol of liberation, e.g. advertisers making an active attempt to link the car to renewed family unity as well as connections to nature, depiction of a high speed car chase in a film (1909), customization of cars for celebrities (1916) Various actors increasingly frame the car in the context of existing social relations, e.g.	Producers, distributors, car clubs and users contribute to the convergence of the cultural meaning of the car around two pillars: pleasure and utility. I ANWB increasingly stresses the car as a necessity starting to articulate a new vision of the car user ("nuclear family")

	media depiction of women in traditional roles around automobiles, the banning of women and blacks from racing etc.	
Regulatory environment ***General trend:*** creation, expansion and standardization of a car-friendly institutional environment	Systematic creation of the road network: Woodrow Wilson signs a Federal Aid Road Act (1916), providing first federal money for road building; Federal Highway Act (1921) provides funding for rural roads State authorities introduce fuel taxation earmarked for road building, facilitating further adoption of the automobile Car industry, dealers and car clubs mobilize as a united lobbying front ("motordom") gradually leading to major changes, e.g. re-designing the urban and rural space to accommodate the car (e.g. the first urban highway projects), wiping out public transport or reducing the role of railway to freight transport Helped by the input of the "motordom" traffic rules and specifications for road-building become gradually standardized on state and federal level Suburbanization: urban developers, engineers and architects design and build auto-dependent suburbs Car clubs take over traffic education in schools with an accompanying shift from drivers' responsibilities to stressing the co-responsibility of drivers and pedestrians Universities and engineers initiate the study of traffic as a specific discipline, e.g. the first course (University of Pittsburgh, 1923), textbook on traffic engineering (1925),	Car clubs, the Royal Institute of Engineers and construction companies start a strong lobby for highways, restricted to motor vehicles only, leading to the National Road Plan, creation of a Road Fund and establishment of the National Road Building Laboratory (all 1927) Following the leadership of ANWB and supported by other stakeholders, including the government, a systematic national road network is built before widespread car diffusion. Clashes between car and railway proponents in newspapers, public meetings, technical debates etc. over the future of the transport system – this eventually results in pushing aside trams in most of the cities and also decreasing the role of trains for inter-local transport but retaining the national rail network, thanks to government subsidies Government aims for coordination among various modes of transport, it wants to navigate a coordination crises ANWB starts gets state mandate to act as a vehicle for traffic education with a gradual stress from blaming traffic victims to stressing the moral responsibility of the driver (and therefore resisting the

	traffic research program (1927)	need for driving tests) The Dutch government introduces regulations requiring car-drivers to take a driving exam as a condition of getting a license (1927)
Transnational community *General trend:* International learning becomes increasingly institutionalized with the centre of gravity gradually shifting to the USA	USA becomes the member of the Permanent International Association of Road Congresses (1908): a meeting place for government officials and engineers leading to a consensus about the need for an increasingly science-led and centralized approach to road-building American participation in two World Wars stimulate both the promotion of liquid fuels (over electricity) for mobility and the development of its road network, e.g. the impact of Hitler's *Autobahn* project on the postwar US Interstate Highway System USA increasingly becomes an example in the meetings of transnational organizations, e.g. regarding painting white stripes on the road	Netherlands becomes the member of the Permanent International Association of Road Congresses (1908): a meeting place for government officials and engineers leading to a consensus about the need for an increasingly science-led and centralized approach to road-building US cars increasingly start to take over the Dutch market, a process that includes the establishment of accompanying facilities (e.g. the Ford assembly factory in Amsterdam in the early 1930s)

Sources used for dates and activities: McShane, 1997; Zeitlin and Herrigel, 2000; Geels, 2005; Mom, 2015; Kanger and Schot, 2016; Mom et al. 2002a, b; Schot et al. 2002; Staal, 2003; Mom and Filarski, 2008; Mom et al. 2009.

4.3 Stabilization of societal embedding in the USA (1946-1970) and Netherlands 1958-1970)

By the postwar era the USA had become a paradigmatic automobile country having managed to construct an environment in which the car had become the rational choice for transportation for short- and long-distance trips in both urban and rural areas. An even more rapid growth followed in the postwar era when the urban working class adopted the car in great numbers (Flink, 1990: 359).

In the Netherlands, the car only became the dominant mode of transport in the late 1950s and 1960s. Like in the USA it became a universal machine used for many purposes. In the Netherlands, the car was increasingly used in the 1960s for visits to relatives and friends, weekend outings, and holiday trips (see Figure 4). Table 3 presents an overview of various societal embedding activities for the stabilization phase in both countries.

Figure 4: Roadside camping and car holidays

Table 3: The *stabilization* of societal embedding of the automobility in United States and the Netherlands

Types of embedding	Manifestations in the United States (1946-1970)	Manifestations in the Netherlands (1958-1970)
User environment *General trend:* massive take-up of the car by the working class, the car has become a new normal	Users continue to tinker with the car as a weekend hobby Users join various car subcultures (e.g. antique automobiles, hot rod, drag racing) in great numbers The form, function and practices of car use have stabilized to the extent that new users can largely adopt existing user routines by imitative learning AAA becomes oriented to representing the consumers: product comparisons, consumer recommendations and road tests become widespread	User adopt motor cycles, scooters and mopeds in large numbers as "poor man's cars" and stepping stones towards the car. This is supported by ANWB and the Dutch Association for Bicycle and Automobile Industry Rise of the do-it-yourself culture: users, especially lower middle and working class, continue to tinker with the car as a weekend hobby Users increasingly adopt the "family car" for social and recreational purposes (e.g. visits to relatives and friends, weekend outings, holiday trips, roadside tourism)
Business environment *General trend:* an environment has been	The largely stabilized preferences of producers and consumers create mutual lock-ins, e.g. producers generally moving towards bigger and heavier cars and omitting safety features but users also rejecting the attempts	Further consolidation of the maintenance infrastructure: ANWB establishes *Wegenwacht*, a nationwide road service organization, especially tailored at road side breakdowns

created in which the car has become the rational choice for short- and long-distance, urban and rural individual transport	to introduce lighter or safer models Entrepreneurs further develop various aspects of the automobile system, e.g. the introduction of automatic car wash, high octane gasoline (both 1946), Kettering engine (1947) and cruise control (1959)	
Cultural environment ***General trend:*** the cultural significance of the car is pervasive, dominant and virtually uncontested	Various stakeholders continuously reproduce the stabilized cultural meaning of the car (e.g. TV advertising, news stories, literature, music, films) but the rhetoric starts to catch up with reality (women and minorities increasingly adopt the car) Local authorities and the general public start to view other sub-regimes as deviant, walking or cycling seen as inferior	Various stakeholder, including producers, car clubs and users, define the automobile as the "family car" ANWB engages in cost-benefit calculations in its journal to demonstrate the economic benefits of the car to prospective users
Regulatory environment ***General trend:*** the regulatory environment has become largely stabilized	The "Road Gang" (an assembly of various stakeholders related to the automobile system), backed by some military sponsors, lobbies successfully for the National Defense and Interstate Highway Act (1956) Consolidation and expansion of the road network (freeways, highways), involving increasing government investment Amplification of the suburbanization boom: more and more individuals prefer to live in suburbs which are auto-dependent by design, reinforced by mutually supportive zoning regulations that separate geographic space into residential, commercial, and industrial segments	Further expansion and consolidation of the road network The government's two National Road Plans (1958, 1968) contribute to a sharp growth in highway construction
General trend: USA has	Society of Automotive Engineering, established in the USA in 1905, becomes	US experts provide advice to shaping the Dutch mobility system on many levels of

established itself as a paradigmatic car country that is imitated by various developed and developing countries with significant local variations	international linking up with different standards bodies and engineering organizations over the world The features of US mobility system (e.g. mass production, corporate forms of organization, distribution channels, user practices) diffuse to Europe by various channels such as Marshall Plan, the Productivity Mission, Fulbright Program or the United States Information Agency, but the uptake is selective and adapted to local conditions	governance; Dutch experts travel to the USA as part of the Marshall plan.

Sources used for dates and activities: McShane, 1997; Zeitlin and Herrigel, 2000; Geels, 2005; Mom, 2015; Kanger and Schot, 2016; Mom et al. 2002a, b; Schot et al. 2002; Staal, 2003; Mom and Filarski, 2008; Mom et al. 2009.

5. Comparison: Similarities and differences in the societal embedding of automobility

In this paper we have proposed that technological diffusion can be analyzed as a process of societal embedding, in which actors make choices that influence the *direction* and *shape* of socio-technical system development. Our two cases reveal that the diffusion environments for the automobile were multi-dimensional, dynamic, and full of actors with (sometimes conflicting) interests, desires, and visions, who interacted, debated, negotiated, and struggled with each other as diffusion paths were being created and enacted. The diffusion of automobiles was thus accompanied by various societal embedding activities in different environments, which together created a socio-technical system in which automobiles could function. Based on both cases, embedding mechanisms are salient in each phase, perhaps with one exception: embedding in the cultural environment seems especially important in the first phase. We begin from highlighting the broad similarities and differences across both cases before discussing each dimension in more detail.

First, roads and car did not diffuse equally fast. In the Netherlands, the creation of a national highway infrastructure in the late 1920s and early 1930s, and its expansion in the 1950s, *preceded* widespread car diffusion, partly because of influences from the road lobby, partly because of recovery plans for the Dutch economy in the 1950s. In the United States, roads evolved more evenly with demand for cars, and in some cases road development lagged behind the diffusion of automobiles, a problem typified by growing traffic congestion, or “traffic snarls,” that began as early as the 1910s (Melosi, 2005). The Interstate Highway System did not fully emerge until well into the 1950s in the United States.

The differences also raise interesting questions about the reversibility of automobility transitions. In the second half of the 1960s the automobility system was increasingly challenged in both countries and both countries also experienced a new cycling boom (Longhurst, 2015). However, whereas Dutch cities managed to reshape urban space to make it friendlier to pedestrians and cyclists, this largely failed to happen in the USA. In other words, the preserved variety in Dutch mobility system made a partial reversal of the process possible, as the percentage of cycling in the total number of urban trips increased since the 1970s at the expense of cars (De la Bruheze and Veraart, 1999).

This leads us to point out a crucial difference between the societal embedding framework and diffusion literature. Whereas the latter tends to focus on single technologies and emphasize quantitative features (speed of diffusion, saturation point of the market), our societal embedding and systems focus involves attention to complementary changes on multiple dimensions (technical, economic, regulatory, cultural) and to outcomes (substantively different mobility systems). Therefore, it can be used to challenge the implicit normativity of the diffusion literature which includes the categories such as late adopters and laggards which would apply to the Netherlands. In an international perspective, this suggests that countries should catch up as soon as they have met some essential preconditions (such as consumer purchasing power). However, as our case study comparison demonstrates, the underlying difference in diffusion of specific technologies may actually reflect differing societal preferences about transport modalities reflected in specific societal embedding processes for supporting them.

5.1 Embedding in the user environment

Both cases show a pattern of co-evolution of (technical) form and (social) function of the automobile. Automobiles did not diffuse into a ready-made environment, where the population of users and their preferences were known in advance. Instead, users gradually developed and constructed preferences and functional requirements.

In both countries, the car began as an “adventure machine,” especially in application niches of racing and touring (complemented with the “technical adventure” of repairs). In the interwar years, the “utilitarian” function was added (for commuting, business, freight) which subsequently led to the “multi-functional” car. Finally, the automobile was translated into a “family car for the masses” (for camping, holidays, social visits) (Schot et al., 2002; Mom, 2015). These changes in functionality were social innovations that were accompanied by evaluations, social debates (in newspapers or user magazines), and gradual acceptance followed by institutionalization

In both countries, national user organizations (AAA in USA, ANWB in the Netherlands) played a considerable role in shaping the mobility system and facilitating the diffusion of the automobile. They articulated positive discourses about cars and new visions of functions and uses (which were disseminated through magazines and demonstrated through shows, tours, and tests) and lobbied for favorable regulations, road investments and unified traffic regulations (Mom et al., 2002a, b; Flink, 1990). This finding resonates with the literature on the importance of (inter)mediation in transition processes (Bush et al., 2017; Kivimaa et al., 2018).

In both countries, car clubs also educated users, articulated new routines and called for civilized driver behavior. People were not born ready to use the automobile. In the eyes of the educators, new groups not only had to acquire new technical competencies (driving, repair), but also new behavioral routines and sometimes new morals. During the interwar years, for instance, new users were taught to behave like gentlemen in traffic. Driving schools and license systems were set up, accompanied by educational campaigns in magazines. This educating work was largely done by the ANWB in the Netherlands, whereas in the USA AAA increasingly took over traffic education in schools from local safety councils in the 1920s (Norton, 2008).

The major difference is that in the Netherlands, the ANWB played a larger role than similar organizations (AAA) in the USA, where sales departments and automotive dealerships played the primary mediating role. The ANWB served as an intermediary between car companies and users. In particular, as spokesperson for car users in the Netherlands, the ANWB communicated experiences and user demands back to the car industry (e.g. preferences for more reliable and user-friendly cars in the Interbellum). In contrast to the USA, the ANWB also took a more active role in building a national road infrastructure (Mom, 2015). For example, in 1946 ANWB founded a road service organization that provided assistance in case of breakdowns and accidents.

5.2 Embedding in business environment

In the business realm, Dutch and American car diffusion entailed the creation of specialized service and maintenance firms (with spare parts and repair skills), which tailored to the middle classes with less technical skills. While early pioneers were capable of tinkering and repairing their own cars, technical competencies later became more distributed. A new "garage infrastructure" had a knock-on effect because it led to a flourishing second-hand market, which further stimulated car diffusion. One notable difference was that the United States developed a strong car industry pushing automobiles, whereas in the Netherlands there was no strong national car industry. However, with the gradual emergence of corporate R&D labs (in the USA), the complexity of car designs increased, which, in turn, gradually led to the decrease in self-repair activities and self-made modifications by users (Franz, 2005).

A suite of business models and financial innovations integrated with cars to further accelerate diffusion (Sovacool, 2009). The development of automobile insurance arose as a mechanism to offer greater security and reduced risk to automobile owners. Dealerships offered consumers an average insurance package consisting of protection against fire, theft, and vandalism, and liability in the case of an automobile accident. Annual auto shows exhibited a variety of cars that could be viewed and ordered from the factory. Manufacturers paid particular attention to the importance of franchise dealerships, who learned to cement a close and lasting relationship with purchasers, especially since early models required constant care and maintenance (particularly when they were driven in rural areas or at high speeds). Finally, advancements in instalment financing expanded the class of eligible purchasers and made models much more affordable. The success of instalment financing plans not only stimulated the interest of banks and financing corporations, but also increased the sale of insurance, which was required to finance vehicles.

5.3 Cultural embedding

Car diffusion was accompanied by substantial societal enthusiasm with societal discourses evolving from distant admiration (racing as popular spectator sport, parading by the rich) to concrete experiences (excitement of driving). The warnings against speed addiction indicate that many drivers found driving a thrilling experience. These experiences and the many advertisements, stories and movies about cars created widespread cultural enthusiasm and latent demand before the masses could even think about buying a car. The positive discourses in both countries created legitimacy for public investments in road infrastructures and exerted pressures on policymakers. Whereas the cultural embedding was largely similar in both countries during the first phase, in the interwar era it began to diverge. In the Netherlands the position of the car became contested, it was not yet seen as the core of the future mobility systems. Its future had to be coordinated with other modes of transport, especially railways. It was thought that trains would be responsible for long distance transport, while the car would be used for shorter trips.

In the postwar era the cultural embedding processes in both countries started to converge again, reflected in rapid adoption of mass produced cars by middle and working class and the accompanying reshaping of rural and urban space to make it suitable for automobiles. The roots of this convergence can be traced to the postwar wave of "Americanization", including the transfer of US mass production technology, corporate structures, business models, management techniques, distribution channels, advertising techniques and consumer profiles to Europe (Schröter, 2007).

5.4 Regulatory embedding

To deal with negative externalities of increased car use (accidents, speeding, dust, congestion), policymakers in both countries introduced various regulations (e.g. speed regulations, traffic rules, traffic police, driver's licenses). They also became increasingly involved in road-building and developed new funding mechanisms, including a road tax law (1926) which replaced many local tolls and included the creation of a national Road Fund (in the Netherlands) and the Highway Trust Fund (in the United States).

The creation of national highway infrastructure in the late 1920s and early 1930s in both countries, and its expansion throughout the 1940s and 1950s, entailed substantial further government support and financial expenditure. Road infrastructures and car diffusion mutually stimulated each other, as more roads increased the appeal of driving, while more cars created a call for more roads.

A crucial lasting difference in regulatory embedding was related to the regulatory and political struggles in the interwar era. In the USA, these struggles led to the complete dominance of the automobile in both rural and urban areas, for short and long distance travel. Policymakers did not actively protect railways, streetcars or public transport. This resulted in the railways being pushed out of passenger transport, the decline of public transport in cities and the construction of car-dependent suburbs. In the Netherlands, however, the outcome of regulatory and political struggles was rather different culminating in the co-existence of multiple regimes for passenger transport. So, the "laggard" status of the Dutch (to use the terminology from diffusion of innovations framework) was not merely a matter of having a lower income than USA, but was also a result of deliberate political choices to sustain multiple modalities, keeping public transport as well as cycling alive as a feasible option, but mainly for the poorer people. Put another way, being a "laggard" in this context represented an active and not necessarily inferior choice.

5.5 Embedding in the transnational community

Both the Dutch and American transport experts were very active in various international platforms from early on. However, in terms of the influence exercised on the future shape of mobility systems, the USA played a considerably greater role. In the emergence phase, international institutions had a strong European flavour. But the centre of gravity gradually shifted to USA in the interwar era. During 1920s and 1930s one could even speak of an emerging divergence between European and US car cultures, which were also reflected in vehicle design (optimized for speed in Europe and comfort in USA), regulations (horsepower vs. fuel-based taxation, earmarking of taxes for road-building in USA from the 1920s) and production principles (mass production being adopted to much greater degree in USA) (Flink, 1990; Mom, 2015).

To a large degree, this distinctiveness began to erode after World War II, when the American car culture became internationally dominant and American traffic engineering became the gold standard pushing for a vision in which cars would be the core element in the transportation system. This led to remarkable similarities between the two mobility systems in terms of traffic infrastructure tailored for cars, prevalence of individually-owned gasoline-based vehicles, and a sharp increase in the adoption of automobiles. This process was considerably facilitated by international institutions (e.g. the Marshall Plan) and channels of influence (e.g. the Fulbright Program), which directly facilitated international exchange of technologies and expertise. Although there had been interactions between Europe and USA before, it was during the post-war era that the transnational community exerted significant influence over the shape and consolidation of national mobility systems. This is reflected in the fact that other countries did not merely imitate USA; the adoption of American principles was uneven and selective, often modified to suit local conditions. Moreover, in some instances the European experience shaped the USA mobility system in turn, e.g. the "Big Three" developing compact car models from the 1950s to avoid the increase in market share of European models (Flink, 1990; Zeitlin and Herrigel, 2000).

6. Implications: Insights for electric vehicles and global sustainability transitions

The societal embedding perspective has direct bearing on the understanding of the future of EVs and other alternative modes of mobility. The benefits of EVs will depend on the actions, choices and struggles in societal embedding processes. Drawing on our conceptual framework and some of the patterns and mechanisms from the historical cases, we will consider contemporary societal embedding processes with regard to EVs in order to better understand their possible diffusion trajectories. These trajectories can have net negative or positive impacts on sustainability. For instance, experts on mobility have suggested that embedding EVs within business and user environments that also encourage walking, cycling, ridesharing and inter-modality can further reduce emissions (beyond just electrification); while EV-use in mobility systems that encourage private, individual driving (especially as a second or third car) can have deleterious impacts on sustainability (Sovacool, 2017: 82). Similarly, a regulatory environment prioritizing fossil-fuelled electricity will result in negative carbon and pollution emissions associated with vehicle charging that are magnitudes of order greater than those regulatory environments that prioritize renewable and low-carbon sources of electricity supply (ibid.). The negative environmental impacts of electric mobility may be especially acute when EVs do not substitute for conventional cars, and are adopted merely as an additional second or third car (Graham-Rowe et al., 2012; Addison et al., 2010).

Tesla, arguably the world's most recognizable or at least popular brand of electric vehicle (Ayre, 2017; Shahan, 2017), illustrates these tensions in practice. Although Tesla's EVs have currently gained much publicity, from the embedding perspective their selling point has been to provide an EV that would roughly match the range of the gasoline vehicle, and thus not disrupt other societal embedding dimensions. Tesla's innovation is thus in the fuel source (electricity rather than petroleum) but not ownership (which remains private), design (it "looks" like a conventional car), and ridership (which is frequently framed as individual, rather than open to ride-sharing). This contrasts with other types of electric vehicles, such as the TH!NK City or Buddy, which consumers depict as "boring," "ugly," and "feminine" (Sovacool et al., 2019). In particular, Renault's Fluence Z.E., which was attached to a mobility-as-a-Service (MaaS) contract with Better Place. This MaaS package required a paid monthly subscription in exchange for the use of Better Place's charging network. It proved to be too much of a "stretch" in terms of design or user preferences (Sovacool et al., 2017). These vehicles did not replicate the functional, societal, or symbolic frames of automobility effectively (Sovacool and Axsen, 2018). Whether Tesla models and other EVs reinforce notions or frames of traditional automobility, or challenge them, depends on the shape and substance of its societal embedding processes.

The future embedding of the EVs will not happen in a vacuum. Instead this process continues to be shaped by deeper historical assumptions about the current mobility system that crystallized iteratively over the 20th century, such as its widespread reliance on individual privately-owned vehicles (leading to under-utilization of vehicle capacity), user preference for long-distance driving capability (despite the fact that most trips are quite short), the continuing status of the car as a luxury item (think of the Tesla Roadster), or the passive role of the user (software by producers dictating the terms of use of the car).

Using our conceptual framework and historical findings, this section assesses contemporary societal embedding processes of EVs worldwide and offers some reflections about future auto-mobility transitions. This inductive analysis suggests that societal embedding activities focus on increasing the number of EVs but less on the wider transport system or challenging underlying mobility practices. We discuss EV developments for all five embedding dimensions, using illustrative (and at times, newly emerging) examples from multiple countries.

6.1 Embedding in user environment

Commercial marketing materials currently frame EVs as offering substitutable or similar performance attributes as conventional vehicles, but with lower emissions (IEA, 2016). So, apart from efficiency (and in some cases greater torque or acceleration), most EVs do not generally entail or offer exciting functionalities that can create enthusiasm (as early cars did compared to train/horse). Nonetheless, drawing on our cases, perhaps more can be made of the smooth, silent driving experience associated with EVs. Recent focus groups in the Nordic region (Kester et al., 2018) and surveys (Sovacool et al., 2018c) have for instance emphasized quietness of ride as one of the top three attributes influencing intentions to purchase an EV. This could enhance the social desirability of EVs among potential adopters who consider non-monetary dimensions to vehicles—such as performance, aesthetics, or comfort—when making purchasing decisions.

Furthermore, Ryghaug and Toftaker (2014) suggest that driving EVs leads to transformative user learning with regard to range planning and greater appreciation of environmental issues. Indeed, the Norwegian Electric Vehicle Association conducted a national survey among EV owners with fairly high response rates (about 33%) and a large sample (7,780 respondents in 2015) (Haugneland et al., 2016), which noted that current EV designs can fulfil most of the traveling needs of drivers; that respondents become more conscious about their energy use after they bought their EV; and that one-quarter state they will consider installing a solar panel on their house. This implies a learning effect where social networks or processes of social influence facilitate pro-environmental behaviour (Axsen and Kurani, 2012, 2014) to accelerate uptake.

There is also (anecdotal) evidence that some people initially do not expect to like their EV, but quickly come to favor it once they start using it. Axsen and Kurani (2013) document how one household they interviewed stated an initial preference for a Hummer (a conventional Sports Utility Vehicle), but ended up loving the Toyota Prius they used in a trial to the point they started using it much more than expected. In Denmark, Jensen et al. (2013: 24) similarly found using a survey and stated preference experiment that "individual preferences change significantly after a real experience with an electric vehicle in the household." And although there does not seem to be a strong user organization (like ANWB in the Netherlands or the AAA in the United States) that collects information and speaks to car manufacturers on their behalf, the World Electric Vehicle Association (WEVA) is growing in its membership and regional groups such as the European Association for Electromobility (AVERE) are also reporting increases in members.

A final way EVs could become further embedded in user environments is via the electrification of fleets or public transport. Professional organisations, especially fleet operators, are increasingly adopting electric vehicles. In 2017, the stock of electric buses increased to 370,000 units (IEA, 2018), the vast majority of which are used by Chinese companies, stimulated by government subsidies and local conversion programmes. The city of Shenzhen, for instance, switched its entire urban bus fleet (16,359 vehicles) to all-electric models and it is now targeting its taxi fleet (IEA, 2018). London in the United Kingdom is also seeking to fully electrify its bus fleet by 2020 according to its "Ultra Low Emissions Zone" program—to make all 300 single decker buses in central London exclusively powered by electricity and/or hydrogen, and for 3000 double decker buses in the greater London area to be hybrid electric (Transport for London, 2015). Other North American and European cities have also begun to switch towards electric buses or engaged in pilot projects, often in response to local air quality concerns. Other fleet operators like utility companies (postal services, gas, water, electricity), retailers, home delivery organisations, car rental companies, and taxi companies are also beginning to adopt electric vehicles to improve their image improvement, tap into new markets, or anticipate future regulations (ICCT, 2016).

6.2 Embedding in business environment

The potential business market for EVs is considerably large, given that it involves both replacing conventional (fossil) fuel sources for mobility as well as the vehicle itself. This creates opportunities for substantial embedding in financial and business environments.

Agassi (2007) for instance projected that the total economic disruption by electric mobility could total as high as $6 trillion a year when one considered a combined global market for fuel, cars and components, financing, electric charging infrastructure, batteries, in-car mobility services (such as navigation) and monetized carbon credits. Looking at only direct sales of cars and maintenance, McKinsey & Company (2017) estimated in Europe that the automotive retail, maintenance and repair business generated about $237 billion in revenues each year. These large numbers underlie a strong potential business or market case for EV diffusion.

A further interesting characteristic (and difference from our historical cases) is that EVs are developed by both incumbent car companies and new entrants (e.g. Tesla, BYD, Think, Buddy). Wells and Nieuwenhuis (2012) write that incumbents long controlled the pace of change (basically keeping it slow), but new entrant activities seem to have accelerated the pace of change in recent years. It is too early to tell who will win; the car industry has very high entry barriers and Tesla is prone to bouts of investor anxiety (Sharma, 2017; Hough, 2018). However, the Volkswagen scandal over cheating diesel pollution tests (and more widespread cheating of emission testing by all car companies) has tarnished their reputation (Gates et al., 2016). Car companies such as Renault, Volkswagen, BMW, and Nissan have in tandem increasingly made ambitious statements that they will more rapidly reorient towards EVs, and they now dominate the European market because of it (See Table 4). As Harald Krüger, Chairman of the Board of Management at BMW, wrote in the most recent annual report for the BMW Group (2018: 18), "Electric mobility is currently our main strategic focus." Even the oil company Shell is starting to diversify and experiment by offering EV charging facilities on their gasoline stations (Vaughan, 2017). The implication here is that EVs are already becoming embedded in the business strategies of both new entrants and incumbent automotive and fuel providers.

As the societal embedding of EVs involves potential new beneficiaries, the emergent mobility system is likely to be shaped by new actors and actor configurations such as public utility or electricity distribution companies (which could further the embedding process). Salisbury and Toor (2016) highlight four ways in which US utilities are facilitating the take-up of EVs: introduction of time-of-use rates, increasing flexibility around demand charges, creation of incentives for vehicles and charging stations, and infrastructure building. EVs also exhibit potential for grid stabilization: for example, Nunes and Brito (2017) have argued that a sufficient amount of EVs would enable to phase out gas power plants from the Portuguese energy mix. New business routines, entailing the inclusion of new actors, are likely to develop around the use of big data for grid and traffic monitoring, including the estimation of charging demand (Arias and Bae, 2016), energy consumption, driving range (Fetene et al., 2017) or driver intent (Birek et al., 2018). This might involve the extension of routines first developed in the ICT sector to the mobility system, i.e. treating user-generated data as a commodity to be sold to new user groups (McKinsey & Company, 2016) further enabling new strategies such as in-car targeted advertising. Other private sector entities such as electricity companies, energy distribution companies, aggregators, charging operators, and supermarkets play relevant roles in EV embedding, but their importance varies across jurisdictions.

Table 4: Top Ten European Electric Vehicle Sales by Make and Model, 2017

No	Brand	Volume of annual sales	EV Market Share
1	Renault Zoe	31,410	10%
2	BMW i3	20,855	7%
3	Mitsubishi Outlander PHEV	19,189	6%
4	Nissan Leaf	17,454	6%
5	Tesla Model S	15,553	5%
6	Volkswagen Passat GTE	13,599	4%
7	Volkswagen e-Golf	12,895	4%
8	Tesla Model X	12,630	4%
9	Mercedes GLC350e	11,249	4%
10	BMW 225xe	10,805	4%

Source: Authors, top panel is modified from European sales data present in Zach (2018)

6.3 Cultural embedding

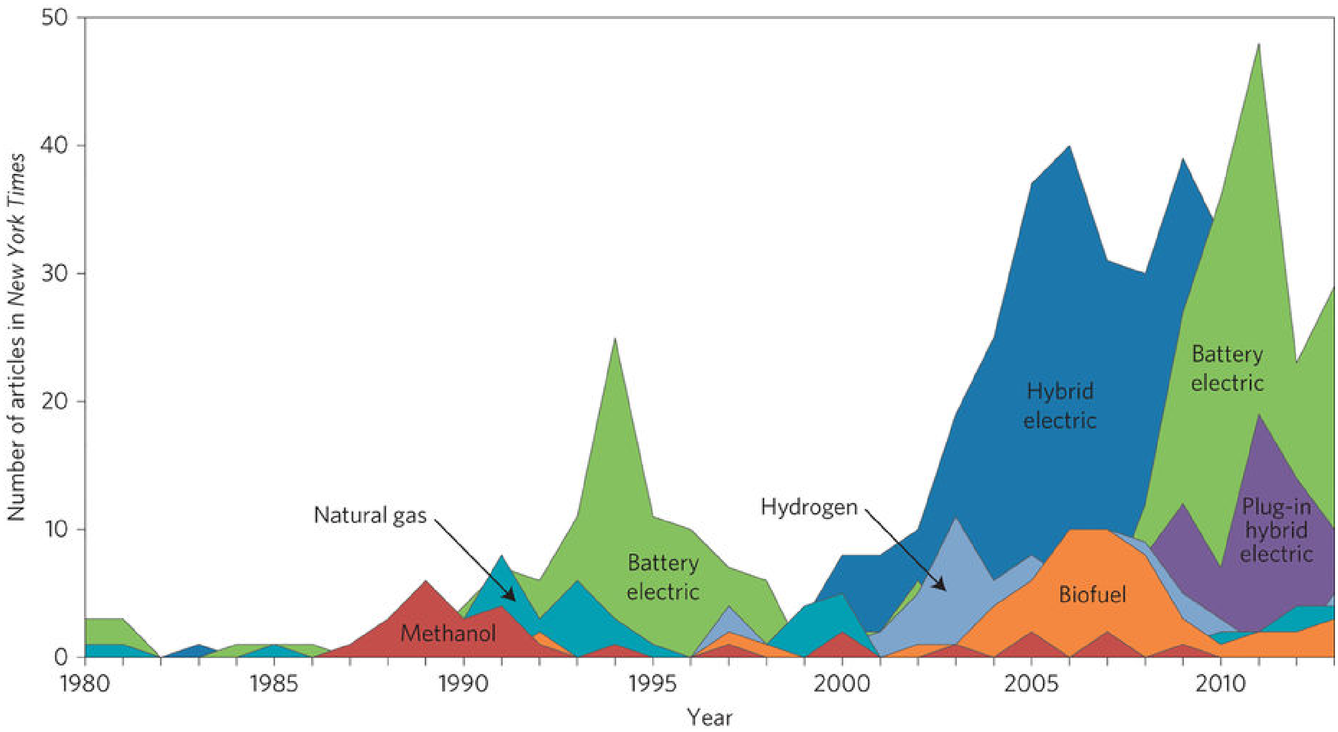
Culturally, the embedding profess is more prosaic, and difficult to identify. However, there are strong expectations that EVs are a promising future low-carbon transport option, especially pushed by some manufacturers and transport ministries. Figure 5 for example shows advertisement from Nissan, Tesla, and BMW extorting that EVs enable “performance with a clean conscious” or the chance to “drive change” and be “zero emissions.” More generally, many users and promoters of EVs have long associated their vehicles with “greenness”, further expressed via lifestyle practices, social media, community relations and interpersonal networks (Axsen et al., 2012; TyreeHageman et al., 2014). This type of social signalling could further embed the notion of EVs as “green cars” symbolized in cultural resources such as the mass media and films.

Figure 5: Electric Vehicle Advertisements from Nissan, Tesla, and BMW

Source: Photographed and compiled by the Authors.

A final cultural factor relates to changes in broader public discourse about the desirability and performance of EVs. As sales have begun to accelerate in some countries, promises and expectations have begun to discursively reinforce electric mobility trends. Wentland (2016) for instance noted two highly positive public discourses around electric vehicles (and vehicle to grid) in Germany, one discussing a vision of an interconnected, highly profitable electricity and mobility system, another describing a scenario where individuals come to enhance their autonomy, ownership, and control over both their vehicles and homes. Bergman (2017) has similarly shown how in the United Kingdom, electric vehicles (mostly through their manufacturing and charging) have become intertwined with stories about economic growth and prosperity. Melton et al. (2016) conducted a review of more than 30 years of media cycles for various low-carbon forms of mobility in the *New York Times*, and noted that battery electric vehicles were clearly entering a peak compared to biofuel, hydrogen, methanol, or natural gas (see Figure 6). That said, the contrast with our historical cases is notable, as for EVs the user is mostly excluded from tinkering with the machine.

Figure 6: Media Cycles Surrounding Alternative Modes of Transport, 1980-2013



The historical cases are instructive, though, by reminding us that even the existence of a broad-based coalition might not be enough to guarantee the take-up of EVs: what is also needed is anchoring the advocated solutions to wider issues in order to secure their legitimacy. For example, in USA a powerful group called the "Road Gang" started to lobby for interstate highways already in the interwar era. Despite the fact that it brought together "oil, cement, rubber, automobile, insurance, trucking, chemical and construction industries, consumer and political groups, financial institutions, and media" (Seiler, 2008: 94) it only succeeded in the 1950s when framing the issue in terms of national security brought support from military leaders and president Eisenhower. Similarly, the future success of EVs is contingent on acts of cultural embedding: stressing the relevance of EVs for combating climate change while resolving important ambiguities regarding their actual contribution to alleviating environmental problems (Jochem et al., 2017) or issues of cyber-security (Mohandes et al., 2018).

6.4 Regulatory embedding

Contemporary EV transitions do seem closely aligned with processes of regulatory embedding. EV diffusion in all countries is heavily supported by policies, including bans on petrol/diesel cars in Chinese cities and pending bans in Paris and London, strong subsidies in European countries or purchasing incentives in the United States. Kester et al. (2018) surveyed the various available policy mechanisms for electric mobility in the Nordic region, and identified more than 40 distinct potential policies across the dimensions of capital costs, infrastructure (such as charging), information and marketing, standards and regulation, and research and innovation.

Such policies, in terms of regulatory embedding, can be critically important in spurring the adoption of EVs. Stokes and Breetz (2018) as well as Heidrich et al. (2017) demonstrate that political factors such as city, state and national policies for EVs can play a determining role in EV diffusion and acceptance. Similarly, Ji and Huang (2018) note the necessity of strong, consistent, and stable policies for Chinese promotion of EVs. In turn, Wolbertus et al (2018), Zhang et al. (2018), Berkeley et al. (2017), and Hardman et al. (2017) all reveal, to varying degrees, how the strength of EV policies moderates and shapes consumer preferences and purchasing patterns. Their research suggests that the design, implementation, scope, and interactions of EV policy strongly influence patterns of EV diffusion.

Adding more nuance to this finding, Wesseling (2016) writes that there is clear correlation between strength of policy support and early diffusion (Norway also offering various non-monetary benefits like using bus lanes, free parking etc.), but also that there may be struggles between national and local policymakers (e.g. about providing recharging infrastructure). Table 5 for instance shows four distinct regulatory environments for electric vehicles across fourteen countries. Such "geographical diversity" can create differing arrays of policy mixes and national environments that can shape particular diffusion patterns for electric vehicles (and other alternatives) (Raven et al., 2017). Additionally, countries with federalist institutional structures, like the USA, can have substantial regulatory variety between states, which means that Table 5 should be read with some caution.

Table 5: Geographic policy variation for electric vehicles, 2008 to 2014

Country	Role of government (policy approach)	Economic interest (turnover car industry/GDP)	Diffusion aspiration (PEV target) 2020)	PEV diffus (% of total) v stock)
Canada	Hands-off	7.4%	3.5%	0.04%
Denmark	Enabling	0.5%	1.8%	0.13%
France	Interventionist	5.7%	6.0%	0.13%
Germany	Enabling	8.9%	2.4%	0.06%
Italy	Interventionist	3.3%	1.8%	0.01%
Japan	Enabling	10.6%	3.3%	0.17%
Netherlands	Enabling	0.5%	2.3%	0.50%
Norway	Enabling facilitator	2.8%	6.7%	1.46%
Portugal	Interventionist	2.5%	10.5%	0.05%
Spain	Interventionist	7.2%	10.5%	0.05%
Sweden	Enabling	7.1%	12.5%	0.17%
United Kingdom	Hands-off	2.7%	4.6%	0.08%
United States	Hands-off	3.6%	4.9%	0.26%

Source: Wesseling, 2016, p. 36. Note GDP = Gross Domestic Product. PEV = Plug-in Electric Vehicle.

A key component of the regulatory environment is whether it permits charging. Policymakers aim to stimulate the expansion of electric charging infrastructures (IEA, 2018), which involves not just public subsidies and direct infrastructure investments, but also debates about standards for different recharging speeds and technical communication protocols (see the next sub-section for more technical details). Standardization struggles entail not only technical-regulatory debates, but also political battles, because different business and user groups have different interests and needs (Schmidt and Werle, 1998). Although the unique nature of these contests will unfold differently across different national contexts, the regulatory embedding environment will certainly be influenced by future struggles over the governance of grid stabilization and demand response, conflicts over distributed resources versus centralized infrastructures, and issues such as privacy, cybersecurity, and financial liability. This injects a degree of uncertainty into any future scenario forecasting or assessment.

6.5 Embedding in the transnational community

Once consolidated, socio-technical systems "lock-in" certain trajectories of change, become path-dependent and turn resistant to change. This means that attempts to transform piecemeal parts of mobility systems are likely to be drawn out and that the role of the transnational community in facilitating these developments cannot be underestimated.

Perhaps the best single example of transnational embedding for EVs relates to the socio-technical co-production of standards for electric mobility, especially ISO 15118 as it structures high-level communication between EVs and Electric Vehicle Supply Equipment (EVSE) (or chargers) (Kester et al., 2019). Work on this international standard began in 2009 when the ISO/IEC 15118 Joint Working Group was formed to define a communication standard for the charging of EVs. One that would be able to deal with both AC and DC charging levels and incorporate vehicle-to-grid options. ISO 15118 builds on IEC 61851, a more basic communication standard, by adding Power-Line Communication to increase the communication features between a car and its charger. ISO 15118 can be categorized as a terminological, design, and procedural standard because it simultaneously structures the communication process (procedural), details the specifications of the necessary components (design), and clarifies definitions and roles (terminological). As Table 6 indicates, ISO 15118 helps steer, coordinate, and embed common charging practices across various diverse countries such as the United States, Korea, Japan, China, and Europe.

Table 6: Overview of the transnational standards behind electric mobility charging

Standard	Focus	Description	Used/intended to be used
ISO 15118 (-2015 1-8)	EV – EVSE	A de-jure standard. Adding high-level communication to ISO 61851, incl. standardized automatic authentication, authorization, load control and billing procedures. Based on Power Line Communication with a HomePlug Green PHY communication protocol.	Globally
SAE J2847 / 1-3	EV – EVSE	A de-jure standard with three parts. Of these parts, 1 (AC charging) and 3 (V2G) are based on SEP 2.0, and	United States

		part 2 (unidirectional DC charging) is based on ISO 15118 and PLC.	
CHAdeMO	EV – EVSE	A de-facto, by now globally recognized, DC Quick charge standard, building on ISO 61851 but then uses alternative hardware (CAN-bus) and CAN communication protocol. Not compatible with ISO 15118.	Japan/Korea and globally through CHAdeMO charging infrastructure
GB/T 27930 (-2015)	EV-EVSE	A de-jure standard. V2G aspect primarily based on SAE J2847, but with CAN based communication protocol based on OEM practice of using ISO 11898.	China
ISO 61850 & ISO 61851	EVSE - Grid	A de-jure standard. Used for low level - (automated) grid communication between and towards electricity substations. Focus on voltage, frequency and duty cycle	Globally
OCPP	EVSE – EVSE Operator	A de-facto standard. Structures data streams between EVSEs and control servers	Open, Western-Europe but spreading
OCHP	Between EVSE operators	A de-facto standard. Structures data streams between EVSE operators and an international clearing house to allow for interoperability	Open, currently Western-Europe
SEP 2.0	Smart grid	Developed by the ZigBee Alliance. General PLC based machine-to-machine communication protocol for energy appliances (incl. EVs) within a smart grid.	United States

Source: Kester et al. 2018b. Note: EV = electric vehicle. EVSE = electric vehicle supply equipment. V2G = vehicle to grid. OEM = original equipment manufacturer. ISO = International Standards Organization. PLC = Power Line Communication.

7. Conclusion

This article has shown that technological diffusion can be fruitfully analyzed as a process of societal embedding. Our framework draws attention to issues that are often neglected in standard adoption models: a) the diffusion of new technologies requires the simultaneous construction of broader socio-technical systems, b) diffusion not only involves users, but also a range of other societal actors (e.g. policymakers, wider publics, user organizations, repair and installation firms), c) functionalities, user groups, and preferences are not known beforehand, but are articulated during the diffusion process, d) the shape of socio-technical systems derives from learning processes, debates, and struggles on the five dimensions of societal embedding, e) embedding on the national level unfolds in parallel to transnational embedding and from a certain point the transnational community starts to exert important homogenizing influence on national-level developments. The two historical cases confirmed these points, while our future-oriented discussion also drew attention to the likely criticality of user, business, cultural, regulatory, and transnational factors in ongoing transitions to more sustainable forms of mobility and electric mobility. The main takeaway here is that, if treated as substitutes for gasoline-based vehicles, the embedding of EVs will likely contribute to incremental advances sustaining the basic logic of the automobility system as it has been defined over the 20th century. Alternatively, when combined with accompanying changes in supporting technologies, business models, regulatory conditions, user practices and cultural meanings, EVs can play an important part in a more fundamental overhaul of current mobility systems, a mobility transition that challenges automobility. In sum, the directionality of future mobility systems depends on the specific ways of societal embedding of EVs.

The societal embedding perspective is particularly relevant for new technologies, which often face a mismatch with existing structures. It is probably less salient for the diffusion of incremental innovations. The findings are based on only two case studies, so conclusions would benefit from incorporating other cases. But since the findings are positioned and linked to broader theoretical literatures, we can claim *analytical* (not statistical) generalization (Yin, 1994)—it does not draw inferences from statistical data to a population, but makes projections about the likely generalizability of findings based on a qualitative analysis of factors and contexts.

When put into the context of emerging contemporary innovations (such as battery electric vehicles), we suggest that policy should focus more robustly on facilitating societal embedding processes, not just subsidizing battery development or EV purchase. More broadly, the conceptual perspective and findings are relevant for contemporary sustainability challenges, like climate change. Accelerated diffusion of low-carbon technologies requires much more attention for societal embedding processes, e.g. the articulation of positive discourses (not just "doom" scenarios), taking stock of changing cultural perceptions (such as the decreasing interest in car ownership and driving licenses among the younger demographic), stronger policies and investments (e.g. in the form of national programs to revamp transport, energy, and housing systems), and stronger user engagement. Users should not only be approached as "buyers" of technologies, but change initiatives should also focus on articulating new routines, behavioral practices and norms.

Additionally, the societal embedding framework suggests that EV diffusion involves multiple agents beyond direct users, who must be enrolled across all five dimensions. Our societal embedding process underscores that new vehicle purchasers, drivers, and passengers matter, but so do automakers and their employees, franchise dealerships, national regulators, electricity suppliers, lobbyists and civil society groups, and local politicians. Given the societal embedding process is multidimensional, our conceptualization of users must also expand beyond consumer. Put another way, societal embedding broadens our notion of actors and agency and calls into question approaches that only focus narrowly on a single section or dimension, e.g. environmental policy or industry strategy. Inventors and designers, financiers, marketers and journalists, and members of international civil society can also shape different elements of the societal embedding process, rather than the most obvious or immediate, such as car purchasers or policymakers.

Furthermore, and essentially, societal embedding reveals that the diffusion of the automobility (and innovations connected to it, like EVs), despite perhaps appearing straightforward in retrospect, are punctuated, take detours, have unintended consequences and evolve in unpredictable ways. Methodologically, the societal embedding framework opens up opportunities for mixed methods research strategies where the assessment of quantitative parameters of innovation (e.g. the number of cars, speed of diffusion) would be coupled with qualitative ones (social interactions in various embedding environments, leading to substantively different socio-technical mobility systems in various locations). Thus, societal embedding demands a more critical and nuanced analysis of both diffusion and transitions. The direction of change, the actors involved, and the process of co-creation is an interactional, multifarious phenomenon. As such, examining, analyzing, and evaluating automobility and electric mobility transitions needs to become more intricate and qualitative.

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